**Detection by Comparison**

- **Process 1**
  - Avg. time for one time-step
  - SPHYNX

- **Process 2**
  - Avg. time for one time-step
  - SPHYNX+GR

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**Ghost Replication (GR): Detection via Partial Replication**

- **Hardware faults** (e.g. bit-flips) can escape hardware detection (e.g. ECC / chipkill) and cause **Silent Data Corruptions (SDCs)**.
- **Ghost Replication**, or GR, consists in selecting SPH particles to replicate (computations and data) on a different process (ghost particles).
- **SDC detection** is then done by **comparing** the data of the original particle against its ghost.

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**SPH Computational Workflow**

```latex
while Target simulated time is not reached do
  1. Build Tree
  2. Find neighbors and smoothing length
  3. Execute SPH interpolation kernels
  4. Find new time-step
  5. Update velocity and position
  6. Compute self-gravity
  7. Exchange halo particle data
end while
```

---

**Inherently Resilient to Faults?**

- Hardware faults (e.g. bit-flips) can escape hardware detection (e.g. ECC / chipkill) and cause **Silent Data Corruptions (SDCs)**.
- **Ghost Replication**, or GR, consists in selecting SPH particles to replicate (computations and data) on a different process (ghost particles).
- **SDC detection** is then done by comparing the data of the original particle against its ghost.

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**Injection and Propagation of SDCs in SPH**

- **A single bit-flip is injected in one particle:**
  - Error in the first 5 decimals (critical)
  - Error in any of the 16 decimals (small)
- **The error propagates to most particles in one time-step.** The main factor is the number of neighbors, typically (10k – 50k) neighbors.
- **The smoothing nature of SPH progressively wipes out small errors, while critical errors propagate quickly and become easy to identify with GR.**
- **As few as 2% of all particles need to be replicated to detect SDCs in any particle.**

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**Ghost Replication Overhead**

- GR has been incorporated in SPHYNX [1] and experiments were done on Piz Daint [2] running the Evrard Collapse [3] test simulation with 10^5 particles and 100 neighbors per particles.

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**References**


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**GR** is scalable, non-intrusive (minor changes in the application) and precise (no false-positives).

- GR can be applied to other particle-based simulations (i.e. N-body, stencil codes, computational fluid dynamics), however this is a topic that deserves further investigation.